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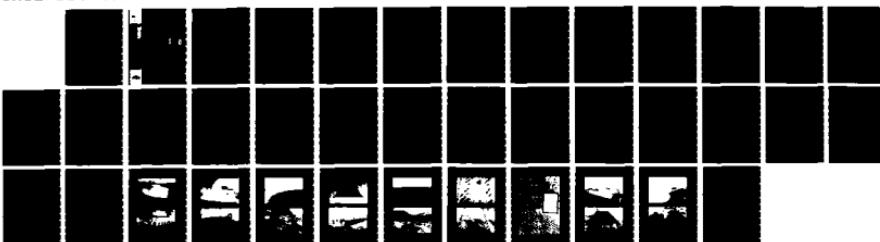
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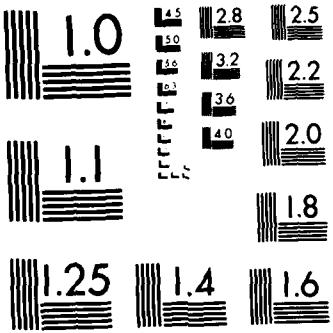
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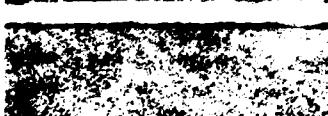
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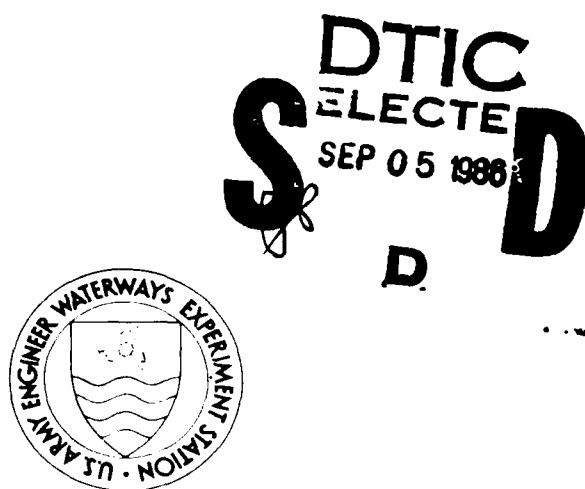
# EVALUATION OF FLEXMAT AS AN ASSAULT EGRESS SURFACING

by

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19 ABSTRACT (Continue on reverse if necessary and identify by block number) River-crossing operations are an integral part of land warfare. The lethality of modern weapons and the capability of large enemy formations dictate that crossing forces reduce their vulnerability by maintaining inherent mobility. Conditions that must be overcome are weak soil strengths, especially at or near the waterline, and exit slopes at streams that are steep and prevent tactical assault vehicles from exiting at the most advantageous location.																
The purpose of this investigation was to develop and evaluate surfacing systems that would satisfy the requirements of the assault vehicle egress role as stated in the Letter of Agreement (LOA) for a tactical bridge access/egress system. Four expedient surfacing (Flexmat) designs were tested and evaluated. Slope-climbing tests were conducted on a typical 25 percent sloped lake bank, and the traffic tests were performed over a heavy clay soil. The Flexmat was then evaluated according to its condition, and the succeeding																
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19. ABSTRACT (Continued).

design was modified to correct any deficiencies that were revealed during the previous test.

The final design of the Flexmat sustained 50 egress passes with the Armored Personnel Carrier, which exceeded the minimum requirement of 25 passes. The condition of the mat after the tests were completed was considered to be excellent.

As a result of this investigation, the Flexmat IV proved to meet the requirements for trafficking and dispensing, as stated in the LOA. However, several recommendations to further improve the system are included in this report.

## PREFACE

This study was conducted under Department of the Army Projects 4A162719AT40 and 4A762719AT40, Task B0, Work Unit 028, and entitled "Access/Egress System for Improved Mobility in Soft Soils," sponsored by the Office, Chief of Engineers (OCE), US Army.

The slope-climbing and traffic tests pertinent to this investigation were performed at the US Army Engineer Waterways Experiment Station (WES) from August 1981 to June 1984.

Engineers of the WES Geotechnical Laboratory (GL) who were actively engaged in the planning, analyzing, and reporting of this study were Messrs. H. L. Green, R. H. Grau, and D. W. White, Jr., and Ms. S. D. Triplett. Engineering technicians for the project were Mr. T. P. Williams and Mr. D. A. Ellison (retired). Mr. Ellison, the initial investigator, has applied for a US Government patent for design of the final surfacing evaluated (Flexmat IV). Messrs. R. Felix, Jr., G. P. Ivy, T. Coffie, W. L. Jones, and G. Anderson are members of the Engineering and Construction Services Division and provided support during the investigation. Overall supervision was provided by Dr. W. F. Marcuson III, Chief, GL, H. Ulery, Jr., Chief, Pavement Systems Division (PSD). This report was prepared by Ms. S. D. Triplett.

During publication of this report, COL Dwayne G. Lee, CE, was Commander and Director. Dr. Robert W. Whalin was Technical Director.



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CONVERSION FACTORS, NON-SI TO SI (METRIC)  
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
inches	2.54	centimetres
pounds (force) per inch	175.1268	newtons per metre
pounds (force) per square foot	47.88026	pascals
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
tons (2,000 pounds, mass)	907.1847	kilograms

## EVALUATION OF FLEXMAT AS AN ASSAULT EGRESS SURFACING

### PART I: INTRODUCTION

#### Background

1. The US Army may find itself at war in any of a variety of places and situations, fighting opponents that could vary from highly modern mechanized forces to light, irregular units in a remote part of the less-developed areas of the world. Wherever the battle begins, the US Army must be equipped, organized, and trained to undertake appropriate military action.

2. River-crossing operations are an integral part of land warfare. The lethality of modern weapons and the capability of large enemy formations dictate that crossing forces reduce their vulnerability by maintaining inherent mobility. The object of any river crossing is to project combat power across a water obstacle while ensuring the integrity and momentum of the force. Therefore, whenever possible, whether in the offense or retrograde, rivers must be crossed in stride as a continuation of the operations using organic, existing, or expedient crossing means. The need for a surfacing over marginal soil materials and on steep bank slopes to expedite military traffic across water obstacles is apparent to maintain the mobility of the force. Tests have shown that an M113 Armored Personnel Carrier (APC) can make only two successful egresses onto an unsurfaced wet slope. Conditions that must be overcome are weak soil strengths--especially at or near the waterline--and exit slopes at streams that are steep and prevent tactical assault vehicles from exiting at the most tactically advantageous location.

3. A Letter of Agreement (LOA) between Headquarters, US Army Materiel Development and Readiness Command (DARCOM), and Headquarters, US Army Training and Doctrine Command,\* was developed to provide requirements for a tactical bridge access/egress system. The major role requirements stated in the LOA are summarized below:

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\* Welker, R. W. 1979. "Letter of Agreement (LOA) for a Tactical Bridge Access/Egress, USATRADOC ACN 38653," Headquarters, US Army Training and Doctrine Command, Fort Monroe, Va.

- a. The assault vehicle egress role must allow swimming and fording combat vehicles to exit streams that have slopes within their normal climbing capabilities (maximum 25 percent). The egress points must be capable of withstanding 25 passes by vehicles up to and including Military Load Class (MLC) 70. The system will enable one squad of an Engineer Combat Company, using current organic equipment, to simultaneously install two egress points, 16.4 ft\* wide and 49 to 66 ft long, within 15 min after arriving at the exit bank.
- b. The bridge equipment access role must provide access lanes for use by gap-crossing equipment to reach bridge launch sites. The access lanes must be capable of withstanding 50 passes by vehicles up to and including MLC 25. The system will enable 10 people from the Engineer Assault Float Bridge Company (ribbon), using current organic equipment, to install single lanes, 13.1 ft wide, at the rate of 328 to 410 ft in 30 min.
- c. The bridge traffic access/egress role must provide roadways capable of withstanding 2,000 to 3,000 vehicle passes (10 percent rated at MLC 70). The system will enable one platoon of the Engineer Combat Company (Corps), using current organic equipment, to install single 13.1-ft lanes at the rate of 820 to 984 ft in 45 min.

4. Studies were conducted to determine if any inventory depot item or "off-the-shelf" commercial items would meet the requirements of the LOA. Eight separate studies conducted at the Waterways Experiment Station (WES) were designed to address major requirements of the LOA for a tactical bridge access/egress system and were consolidated into one report (Carr et al. 1980).\*\* Each of the studies was described previously in a WES Memorandum for Record, a draft report, or a draft user's manual; that report summarizes the early test results and documents the work in chronological order. Each in-house report was presented as an appendix. Another study evaluated two commercial products used as tactical access/egress systems (Ellison 1982).† Results of these studies revealed that no military inventory item or commercial item tested would satisfy all the requirements of the LOA.

5. Another study was conducted in 1980 to determine if any inventory

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\* The requirements of the LOA were originally stated in the SI system. However, in this report all units are in the English system and a conversion chart is included on page 3 for those who wish to use it.

\*\* G. L. Carr, et al. 1980. "Tactical Bridge Access/Egress Preliminary Investigation." US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

† Dave A. Ellison. 1982. "Evaluation of Sod Saver Blocks and M. C. Gill Panels for Tactical Bridge Access/Egress Applications," Miscellaneous Paper GL-82-17, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

items would meet the assault vehicle egress requirements for riverine crossings as listed in the LOA (Carr and Willoughby 1980).\* Test results indicated that none of the materials tested would meet all the requirements, but a neoprene-coated nylon membrane used in conjunction with mats or other materials might satisfy the assault vehicle egress role as stated in Part A of the LOA.

Purpose

6. The purpose of this investigation was to develop and evaluate surfacing systems that would satisfy the requirements of the assault vehicle egress role, as stated in the LOA given in paragraph 3.

Scope

7. Four expedient surfacing designs were tested and evaluated. Slope-climbing tests were conducted on a typical 25 percent sloped lake bank, and the traffic tests were performed over a heavy clay (CH) soil. The surfacing was then evaluated according to the vehicle's ability to egress over the surfacing and the damage it caused in doing so, and the succeeding surfacing design was modified to correct any deficiencies that were revealed during the previous test.

Definition of Pertinent Terms

8. For information and clarity, certain items used in this report are defined as follows:

- a. California Bearing Ratio (CBR): A measure of the bearing capacity of the soil based upon its shearing resistance. CBR is calculated by dividing the unit load required to force a 1.95-in.-diam piston into the soil to a depth of 0.1 in. by the unit load required to force the same piston the same depth into a standard sample of crushed stone, and then multiplying the result by 100.
- b. Pass: One trip of the test vehicle across the test section.

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\* G. L. Carr and W. E. Willoughby. 1980. "Traffic Slope Test of Military Inventory Items and Their Effectiveness in Riverine Egress Test," Miscellaneous Paper GL-80-17, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

- c. Test section: A prepared area on which the test materials are placed for tests.
- d. Wheel path: Area of test section that right or left wheels of the test vehicle traversed as the vehicle moved over the test section.
- e. Flexmat: An expedient surfacing developed by WES to satisfy the requirements of the assault vehicle egress role.

#### Test Vehicles

9. During this investigation, three test vehicles were used to simulate military vehicular traffic. An APC, as shown in Photo 1, was used to conduct all the slope climbing tests. The weight of the APC used for each test is given in Table 1. Traffic tests were conducted using the APC, an M48A1 tank loaded to 140,000 lb, and a ribbon bridge transporter loaded to 47,400 lb. The tank and the transporter are shown in Photos 2 and 3, respectively.

## PART II: TEST I

### Construction Materials

10. The initial design for the Flexmat specified that the mat be 14 ft wide by 40.33 ft long and constructed of galvanized steel wire fabric, single-ply neoprene-coated nylon membrane surfacing (T16), and oak planks. A graphic representation is shown in Figure 1. The woven-wire fabric provides traction for a tracked vehicle egressing a muddy stream, and the membrane waterproofs the existing slope and allows water tracked up the slope by the egressing vehicle to be channeled back into the stream without causing additional weakening of the soil. The 1- by 4-in. oak planks were placed on the under side of the membrane and spaced on 12-in. centers to serve as cleats to help anchor the mat on the slope. Two pieces of 9-gage wire fabric were spliced to form the 14-ft width necessary and placed over the membrane. One-inch staples were then used to fasten the T16 membrane and the wire fabric to the oak planks. To facilitate positioning into the water, weights were attached to the mat. The completed Flexmat ready for transporting and deployment is shown in Photo 4.

11. For the convenience of the reader, Table 2 identifies the various materials used in construction of the four Flexmat designs, and Figures 1-4 show each design graphically.

### Test Procedure

12. During August 1981, slope-climbing tests were conducted on Flexmat I at Brown's Lake located at WES. The test team used a forklift to transport the roll of Flexmat I to the north end of Brown's Lake and then positioned it at the top of a 23 to 25 percent slope of lean clay that extended 30 ft into the lake. The location of the test site and the preparation of the slope was the same for all four tests.

13. The mat was allowed to unroll down the slope with approximately 20 ft extending into the water and sinking to the lake's floor. To prevent slipping, the mat was anchored with seven 2-ft-long anchors. The team drove three anchors into each side of the mat and one at the top in the center. Two men were sent aboard a boat into the lake to ensure that the mat had unrolled

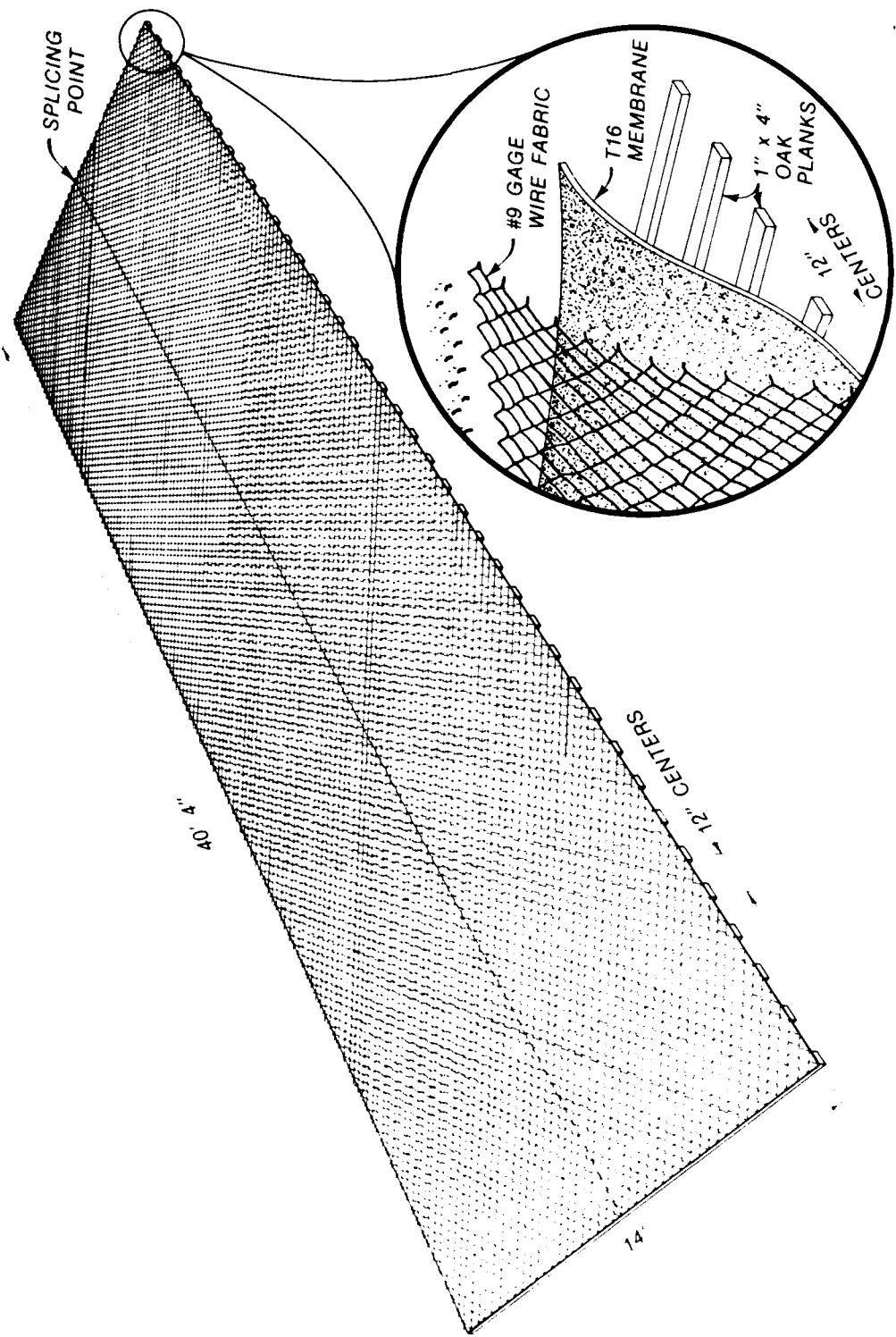


Figure 1. Graphical representation of Flexmat 1

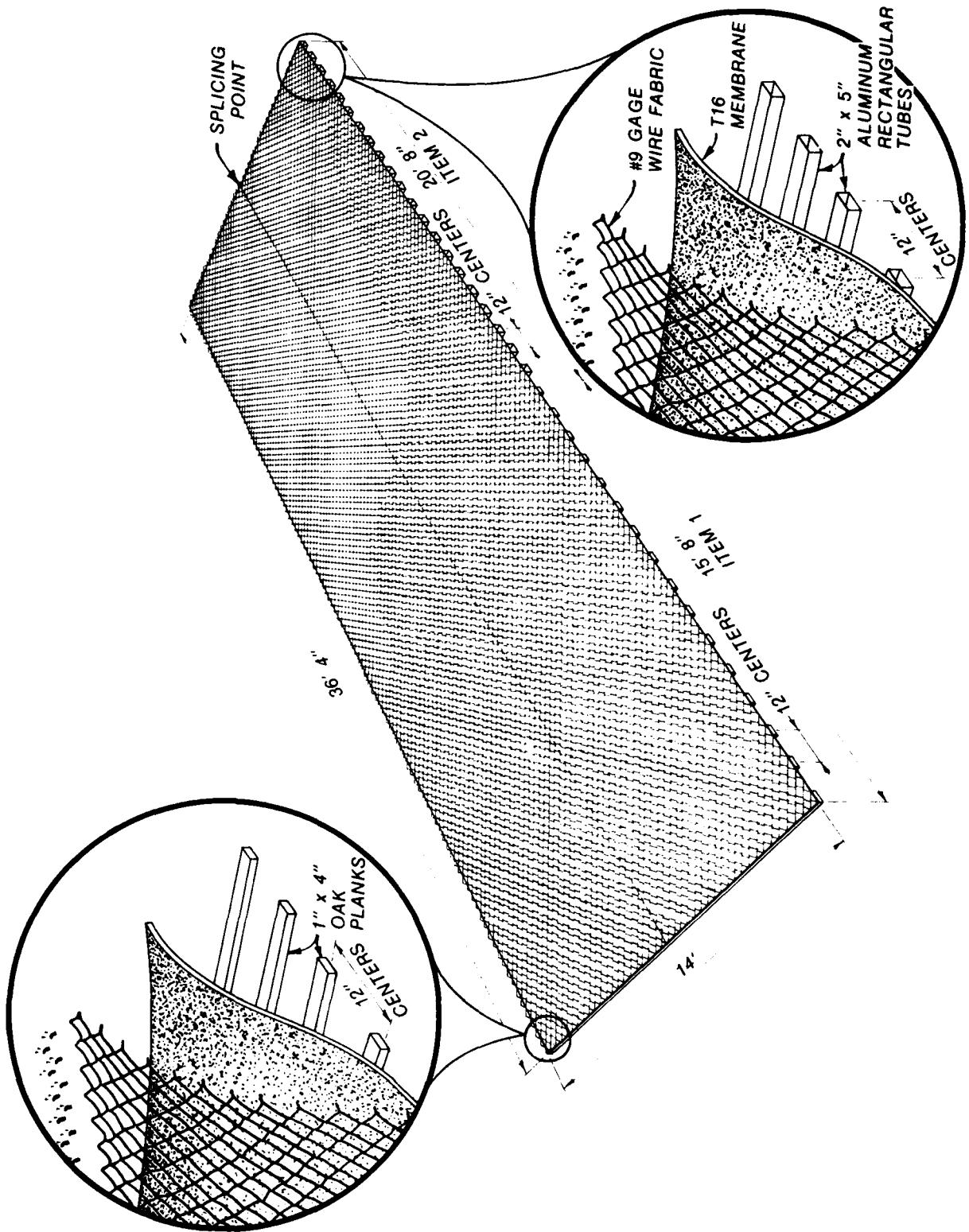


Figure 2. Graphical representation of Flexmat II

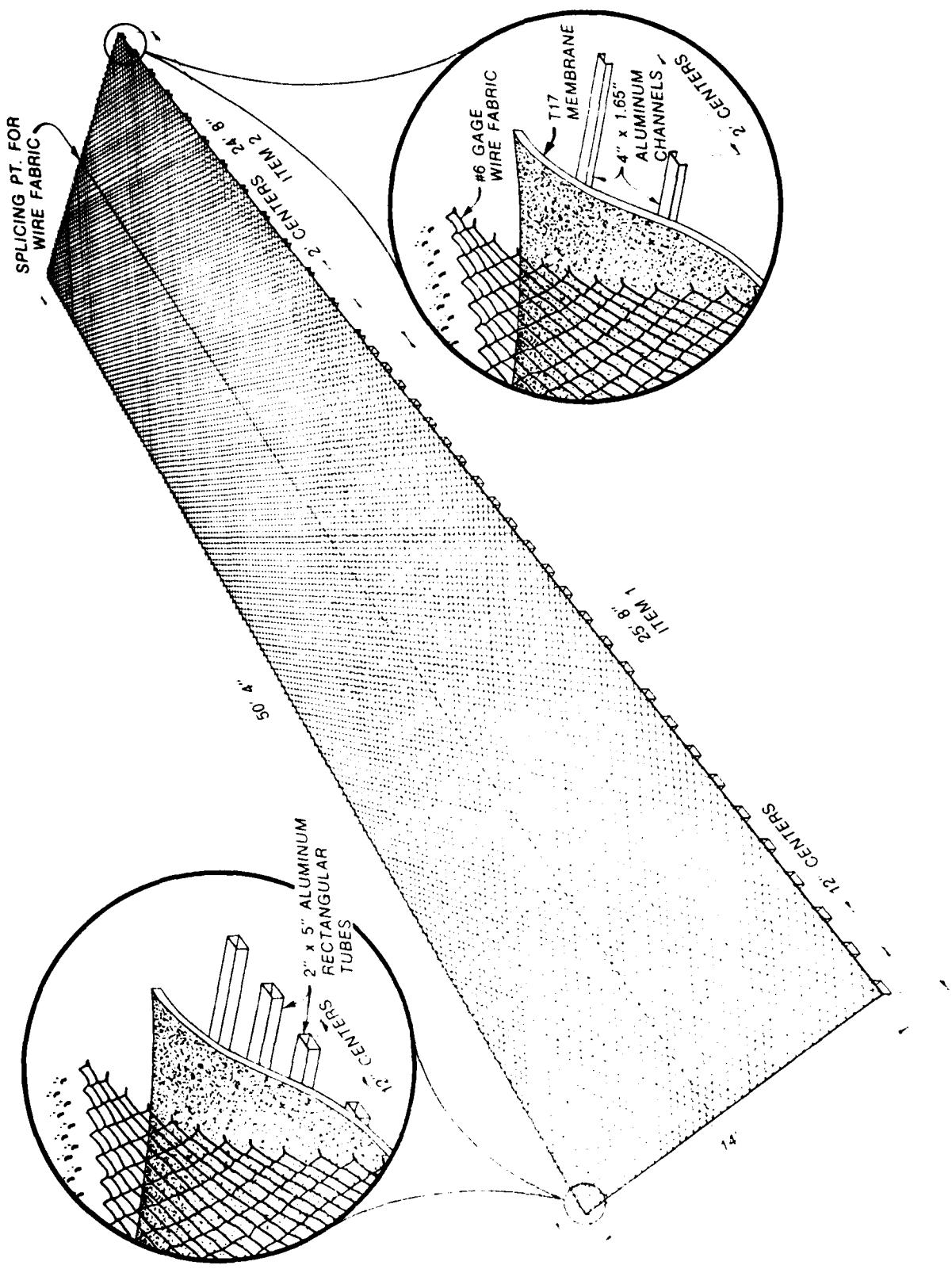


Figure 3. Graphical representation of Flexmat III

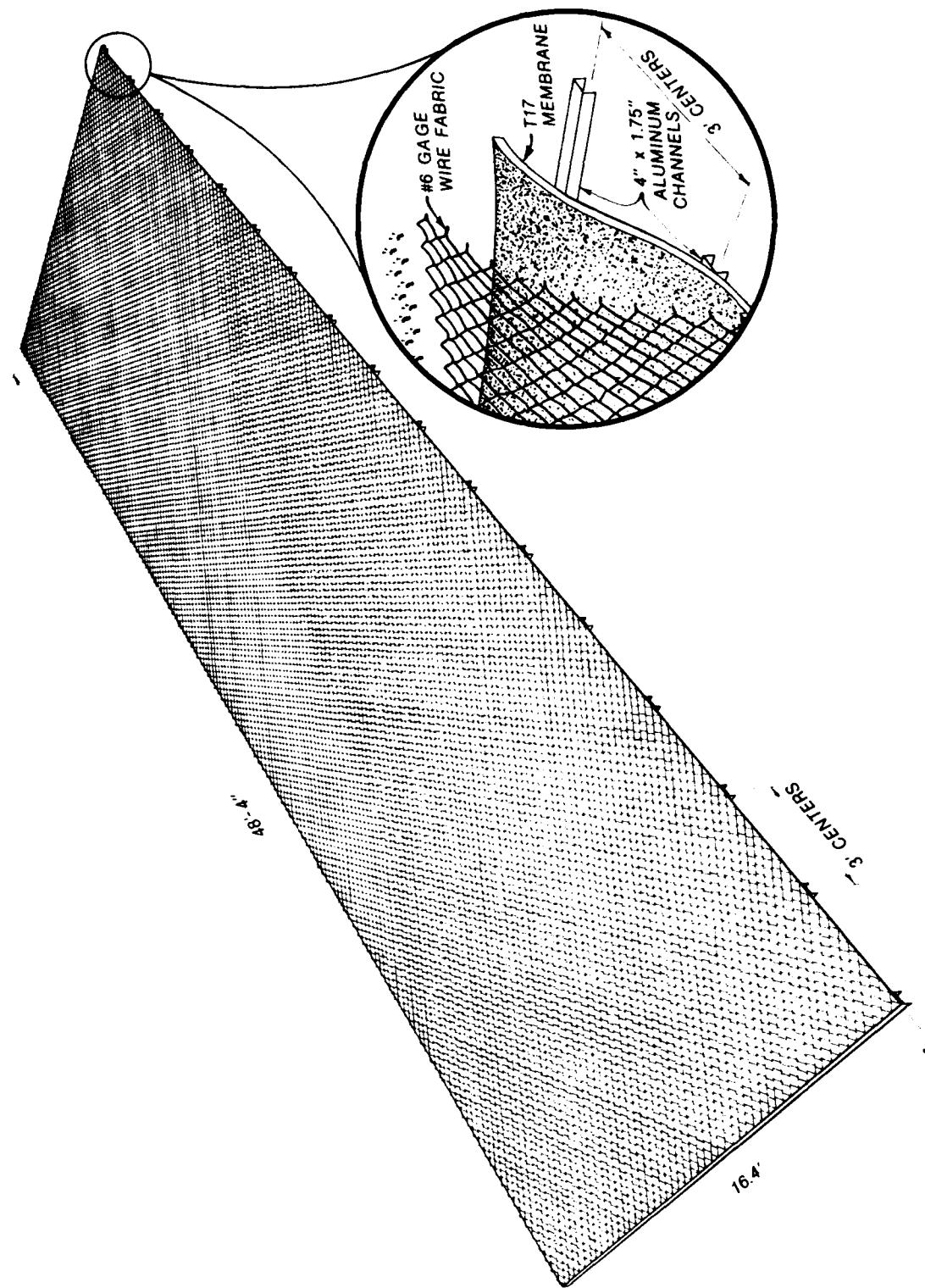


Figure 4. Graphical representation of Flexmat IV

completely under water. The total time for four men to completely install the mat was 12 min. Photo 5 shows Flexmat I in place at the testing site ready for slope-climbing tests.

14. The test team drove over the Flexmat-surfaced slope with an M113 APC loaded to a weight of 23,500 lb. As the driver of the vehicle exited the water onto the mat, the mat became taut and the APC climbed the slope successfully. Due to the shallow water in the test area, maneuvering the APC into alignment with the mat was difficult for the driver. Several attempts were made by the driver to exit the lake with the vehicle and approach the mat from an angle, causing only one track to be in contact with the mat. The test driver had to then retreat and realign the vehicle with the mat. This "seesaw" action created stresses that resulted in premature failure of the immersed section of the mat. The test team discontinued traffic after 12 passes.

15. Table 1 compares parameters involved in the test procedures for the various Flexmat designs.

#### Test Results

16. During the test, some of the oak planks were broken while others were pulled completely loose from the wire fabric and membrane and floated to the surface of the water. With the appearance of failure of the mat below the water, the test team discontinued traffic after 12 passes. The mat was then removed from the water and inspected by the testers.

17. After the final pass was made with the test vehicle, the team found that the 20-ft long portion of the mat on the slope was in excellent condition. However, the part of the mat that had been immersed had sustained severe damage. Several staples had been pulled out or broken causing the wire fabric to separate from the oak planks along one side and down the center where it had been spliced. The membrane was also separated from the oak planks and torn in several places. A general view of the damaged mat after removal from the lake is shown in Photo 6.

## PART III: TEST II

### Construction Materials

18. The Flexmat that the crew used in the second series of tests was a combination of two designs spliced to form a single unit 14 ft wide and 36.34 ft long. The first section, Item 1, was 15.67 ft long and was an undamaged portion of the Flexmat that lay above the waterline in Test I. The second section, Item 2, was 20.67 ft long and was a modified version of the original Flexmat I with the same basic design. The team replaced the oak planks originally specified with 2- by 5-in. aluminum rectangular tubes. Adhesive was used to bond the membrane to the aluminum tubes and the wire fabric was held in place by adjustable stainless steel hose clamps, as shown in Photo 7. A graphical representation of Flexmat II is shown in Figure 2. The completed Flexmat II was rolled into a single roll by the crew for transport to the test site.

### Test Procedure

19. During September 1982, the test team conducted slope-climbing tests on Flexmat II at the WES lake test site. A forklift was used to transport the roll of Flexmat II to the test site, and five men positioned it at the top of the prepared slope. Several men held two ropes looped around the mat for control as they guided the Flexmat down the slope (Photo 8). A 6- by 6-in. 2-ft-long wooden block was placed across the center of the mat to position it at 20 ft above the waterline. The men removed the ropes and cut the bands around the roll. The workers then removed the wooden block and the mat rolled down the slope into the lake. Item 1 remained on the slope above the waterline, and Item 2 was submerged. Anchors were installed and the portion of the mat located below the waterline was checked by the men using the same procedure as in Test I (see paragraph 13). Using five men, complete installation of the mat required a total time of 10 min.

20. The team trafficked the Flexmat-surfaced slope with an M113 APC loaded to a weight of 22,600 lb. During the first egress of the APC, the mat became taut and appeared to be in more stress along one edge than the other. The added stress was believed to be caused by an old rut or hole below the

waterline. The added stress resulted in a 4-ft rip in the membrane, five broken clamps, and one bent aluminum tube. One of the seven anchors was also pulled loose, and although the wire fabric was stretched severely, it was not broken. After the required 25 egresses, the 25 percent slope had increased to a 50 percent slope at the waterline due to the APC traffic. Traffic was then discontinued.

#### Test Results

21. After the team completed the slope-climbing tests, they pulled the Flexmat II from the lake and examined it for damage. The 15.67-ft section of the mat from Test I that remained on the slope above the water was undamaged except for a few staples near the center line that had been pulled out (Photo 9). The section of mat near the waterline sustained severe damage including two aluminum tubes that had pulled completely away from the membrane and wire fabric, one broken tube, and numerous broken clamps. On the lower 13 ft of the mat, the membrane and the beams remained intact and even though the wire fabric was distorted and pulled loose, there were no actual breaks. Photo 10 is a close-up view of the damaged section of Flexmat II. Although the Flexmat II was damaged, it did meet the requirement of 25 egresses.

PART IV: TEST III

Construction Materials

22. The Flexmat designed for the third series of tests consisted of two items that formed a single unit 14 ft wide and 50.34 ft long. The No. 6 gage galvanized wire fabric was replaced by the No. 9 gage used in the two previous designs. The membrane was also changed from single-ply T16 to a heavier two-ply version (T17). The components of Flexmat III are shown graphically in Figure 3.

23. Item 1 was 25.67 ft long and had 2- by 5-in. aluminum rectangular tubes spaced on 12-in. centers. Item 2 was 24.67 ft long, but 4- by 1.65-in. American Standard aluminum channels spaced on 2-ft centers were used to replace the rectangular tubes. Self-drilling and tapping hex head screws 1/4 by 3/4 in. were used with 2- by 3/4-in. aluminum clips in Items 1 and 2 to fasten the Flexmat III. The spacing of the aluminum clips used for Items 1 and 2, however, was different and is shown in Photos 11 and 12, respectively. After fabrication was completed, the Flexmat III was rolled into a single roll for transport to the test site.

Test Procedure

24. During September 1983, the test team conducted slope-climbing tests on Flexmat III. The team transported the mat with a forklift to the test site and positioned it using the same procedure as that described in Test II (see paragraph 19). The time required for five men to complete the installation was 13 min. The test vehicle used for all parts of this test was an M113 APC loaded to a weight of 24,800 lb.

25. In Part A of the third series of tests, Item 1 was placed underwater and 25 egresses were completed with the test vehicle.

26. For Part B, the ends of the mat were reversed and another 25 egresses were completed with Item 2 submerged.

27. The objective of Part C of the experiment was to determine the ability of the Flexmat III to secure its position without any external anchors. The anchors were removed and the APC made three passes over the mat. With Item II above the waterline, the weight of the test vehicle caused the

channels to dig into the slope and prevent slipping.

28. For the last part of the test, Part D, the mat was again in the original position with Item 1 underwater. The objective of this particular test was to simulate the test vehicle with a roll of Flexmat on the rear of the vehicle making a backward egress out of the water onto the mat. To accomplish this effect, the crew moved 2,000 lb of weight from the cargo area to an area 4-1/2 ft from the rear of the APC. The driver then made a successful backward egress from the lake and up the slope with the modified vehicle.

#### Test Results

29. After 25 passes were completed in Part A of the test, the team removed Flexmat III from the lake and examined it. The only damage sustained by the mat was along the center line where the wire fabric had been pieced together. Photo 13 shows where the wire fabric had pulled apart due to the test traffic.

30. Upon completion of an additional 25 egresses in Part B of the test, the condition of the mat had not changed, but the slope at the waterline had increased from 25 to 50 percent.

31. In Part C of the test, the crew examined the ability of the mat to anchor. The test vehicle made three egress passes over the unanchored mat with less than 1 in. of movement. However, these results must be considered inconclusive, since the soil had been compacted by the previous 50 passes of the test vehicle.

32. After Part D of the test was completed, no additional damage was noticed above the waterline. The Flexmat III was then pulled from the water by the crew and inspected again.

33. Most of the wire fabric damage was considered minor and was confined to the center line where the two pieces were spliced. The outside edges were also damaged in places where the test vehicle had made an incorrect approach from the side. After making numerous passes with the test vehicle, the wire fabric became flattened causing the screw heads to be exposed to the cleats of the vehicle's tracks. This resulted in some of the screws being pulled out and others shearing off, thus causing some of the aluminum clips to fall off the mat.

34. The only major damage to the mat occurred when the test vehicle

made a side approach to the mat. The vehicle's tracks became entangled underwater with the wire and beams causing a 2-ft rip in the wire fabric and membrane, shown in Photo 14. Also, two aluminum channels were deformed and one was broken. Although this damage was severe, it was limited only to a small area and did not affect the performance of Flexmat III. Photo 15 is a general view of the mat after all testing had been completed, a total of 57 passes.

## PART V: TEST IV

### Construction Materials

35. The fourth design of the experimental egress surfacing, Flexmat, was 16.4 ft wide and 48.33 ft long. Nominal 4- by 1.75-in. aluminum channels spaced on 3-ft centers supported layers of T17 membrane and wire fabric. The No. 6 gage aluminum-coated wire fabric was one continuous piece with the same dimensions as Flexmat IV. The components of Flexmat IV minus the self-deploying masts are shown in Figure 4. Self-drilling and tapping Phillips pan head screws (1/4 in.-14 Unified National Coarse (UNC) by 1 in.) were used with 2- by 3/4-in aluminum clips to fasten the wire fabric and membrane to the channels. The Phillips pan head screws replaced the hex head screws used in the two previous designs to prevent the APC tracks from damaging the exposed screw heads.

36. A self-deploying visual marking system was added to the design to enable the driver of the test vehicle to align the APC with the mat. An 8-ft-long, 3/8-in.-diam fiberglass mast was threaded through an 11-in.-long, 5-in.-diam floating marker and attached to each corner of the mat that would be submerged. The system was designed so the masts would roll up inside the Flexmat IV for storage and would automatically spring up when the mat unrolled into the water.

### Test Procedure

37. The test team transported the Flexmat IV to the test site and installed it on the sloped ramp using the same procedure as that described in Test II (see paragraph 19). For the anchoring system, four 1-ft-long tack anchors were positioned along the top edge and replaced the seven 2-ft-long anchors used previously. Five man required 13 min to make a complete installation of the Flexmat IV. Photo 16 shows the installed mat with the guide markers deployed.

38. In Part A of the test, the team trafficked the Flexmat IV-surfaced egress test area with an M113 APC loaded to a weight of 24,800 lb. During the first egress, the four 1-ft-long anchors at the top of the Flexmat IV pulled out of the ground allowing 7 ft of the mat to be pulled into the

water. During the next two passes, the vehicle pulled 11 ft more of the Flexmat IV into the water. Since only 12 ft of the mat remained out of the water after three passes, the workers stopped the traffic tests and towed the Flexmat back to its original slope position and reanchored it with four 2-ft-long tack anchors (evenly spaced along the top edge). Traffic was then continued for a total of 20 passes without any damage. On the 21<sup>st</sup> pass, the driver of the APC overran one of the guide markers and the vehicle track became entangled with the ends of two support beams. Only minor damage resulted and normal traffic testing was resumed until 25 passes were completed. At the conclusion of the traffic, underwater slope determinations indicated a 50 percent slope at the waterline. The Flexmat IV was then pulled from the lake and inspected, resulting in a damaged section approximately 6 ft long being removed.

39. The team reversed the ends of the mat for Part B of the test and again installed it on the slope using four 2-ft anchors to hold it in place. Twenty-five additional passes were completed, and the mat was then pulled from the lake and inspected for damage.

40. For Part C of this test, the 16.4- by 42-ft mat was removed from the slope-climbing test site and transported to a low-bearing-strength-soil test section located in a hangar at WES. The soil test section was 24 ft wide, 42 ft long, and 2 ft deep and consisted of a heavy clay (CH) material that had an average bearing strength of 1.9 CBR. The mat was anchored on the sides with 1,000 lb steel weights placed on 2- by 12-ft panels of landing mat.

41. Three military vehicles were used to determine the ability of the Flexmat IV to withstand traffic. The first vehicle trafficked on the mat was the APC loaded to 24,800 lb. After a total of 25 passes, the ruts in the subgrade ranged from 0.4 to 1.0 in. Next, the testers trafficked with the 140,000-lb M48A1 tank. As the driver passed the tank over the test section, an upheaval occurred in the subgrade between the tank's track paths. During the sixth pass, the tank's undercarriage tore an 18-in.-diam hole in the wire fabric. This damage caused the tank traffic to be discontinued. Traffic tests were completed with 50 passes of a ribbon bridge transporter loaded to a weight of 47,400 lb and a tire pressure of 50 psi.

### Test Results

42. The Flexmat IV sustained 50 egress passes with the APC, exceeding the LOA requirement of 25 passes, and the overall condition of the mat was considered to be excellent. Examination of the mat revealed only one small break in the woven wire fabric. This break occurred during Part A of the test when the APC's track became entangled with the support beams. Deflection measurements made on five of the beams showed a maximum permanent deflection set of 7 in. occurred in two of the beams.

43. During the traffic tests, the APC caused ruts in the subgrade that ranged from 0.4 to 1.0 in., but caused no additional damage to the mat. The tank traffic followed and increased the ruts by 0.5 to 2.3 in. During the sixth pass the tank's undercarriage caught the Flexmat IV in an area where upheaval had occurred and tore an 18-in.-diam hole in the woven wire fabric. Tank traffic was then discontinued, and 50 passes of a ribbon bridge transporter were applied to the Flexmat with no additional damage. However, the rut depth increased to as much as 1.0 in. in places. Photo 17 shows the condition of the mat after all traffic (81 passes) were completed.

PART VI: DISCUSSION OF RESULTS, AND CONCLUSIONS  
AND RECOMMENDATIONS

Discussion of Results

44. An analysis of the results obtained in the series of tests performed on the four Flexmat designs yielded conclusions from which recommendations can be made.

45. Oak planks were the first type of support members tried by the test team. Weights had to be attached to the wooden planks to prevent them from floating to the surface of the water. Consequently, aluminum rectangular tubes were tried next, but, because they were heavy and had a smooth flat bottom, they did not help to anchor the mat. Aluminum channels were chosen for the final design since they reduced the weight and facilitated anchoring by embedding the flanges into the soil as the test vehicle passed over the mat. Initially, T16 neoprene-coated nylon membrane was chosen for use in the Flexmat; however, tears were caused easily and, by the third design, the single-ply T16 was replaced with a heavier two-ply T17 version.

46. The majority of damage to the wire fabric in the first three tests occurred along the center line where two pieces of fabric had been spliced to form the necessary width. The final design called for a continuous piece of wire fabric that resulted in a significant decrease in the amount of damage incurred.

47. A variety of fasteners were used to connect the membrane and wire fabric to the support members. The staples as well as the glue and hose clamps proved ineffective. The aluminum clip introduced in the third design worked satisfactorily, but a problem developed with the APC's tracks shearing off the tops of the hex head screws used to hold the clips in place. Once Phillips pan head screws were substituted for the hex head, the problem was resolved.

48. A major part of the damage to the Flexmat during the tests was caused by the driver of the APC approaching the mat from an incorrect angle. To avoid this problem, a visual marking system was added to the fourth design to guide the driver into a correct approach.

### Conclusions

49. The results of this study have yielded the following conclusions:
- a. The Flexmat IV will provide adequate traction for the M113 APC to make 25 successful egresses at exit bank egress points with slopes up to 25 percent.
  - b. A 16.4- by 48.33-ft piece of Flexmat can be installed by five men in less than the required time of 15 min.
  - c. The Flexmat IV, when placed on a low-strength soil, will withstand 75 passes of mixed APC and ribbon bridge transporter traffic.
  - d. A continuous piece of wire fabric prevents premature failure of the mat due to damage caused by a spliced section of wire fabric separating.
  - e. A visual marking system preserves the life of the Flexmat by assuring correct approaches and should be used at all times.

### Recommendations

50. Based on the test results obtained in this study, the following recommendations are warranted:

- a. Additional studies should be made on an anchoring system for the Flexmat.
- b. The possibility of using a helicopter to deliver the Flexmat to the deployment site should be explored.

Table 1  
Comparison of Test Parameters

Test	Date	Percent Slope	Subgrade	Test Vehicle		No. of Passes	No. of Men	Time Required to Position Mat, min
					lb			
I	8/81	25	Lean clay	M113 APC	23,500	12	4	12
II	9/82	25	Lean clay	M113 APC	22,600	25	5	10
III	9/83	25	Lean clay	M113 APC	24,800	57	5	13
IV	5/84	25	Lean clay	M113 APC	24,800	51	5	13
IV	6/84	0	Heavy clay 1.9 CBR	M113 APC	24,800	25	N/A	N/A
IV	6/84	0	Heavy clay 1.9 CBR	M48A1 tank	140,000	6	N/A	N/A
IV	6/84	0	Heavy clay 1.9 CBR	Ribbon bridge transporter	47,400	50	N/A	N/A

Table 2  
Materials Used to Construct Flexmats

Design	Wire Fabric, Gage	Membrane Surfacing	Support Members			Fasteners	Mat Size, ft	Weight lb/sq ft
			Type	Spacing	Length			
I	9	T16	1- by 4-in. oak planks	12-in. centers	1-in. staples	14	40.33	2.78
II Item 1	9	T16	1- by 4-in. oak planks	12-in. centers	1-in. staples	14	15.67	2.78
Item 2	9	T16	Aluminum rectangular tubes, 2 by 5 in.; wall thickness, 0.125 in.	12-in. centers	Adhesive and adjustable stainless steel hose clamps	14	20.67	2.57
III Item 1	6	T17	Aluminum rectangular tubes, 2 by 5 in.; wall thickness, 0.125 in.	12-in. centers	Aluminum clips, 2 by 3/4 in.; self-drilling and tapping hex head screws, 1/4 by 3/4 in.	14	25.67	4.44
Item 2	6	T17	Aluminum channels, American Standard, 4 by 1.65 in.; web thickness, 0.247 in.	2-ft centers	Aluminum clips, 2 by 3/4 in.; self-drilling and tapping hex head screws, 1/4 by 3/4 in.	14	24.67	2.29
IV	6	T17	Aluminum channels, 4 by 1.75 in.; web and flange thickness, 0.188 in.	3-ft centers	Aluminum clips, 2 in. by 3/4 in.; self-drilling and tapping Phillips pan head screws, 1/4 in. - 14 UNC by 1 in.	16.4	48.33	2.21

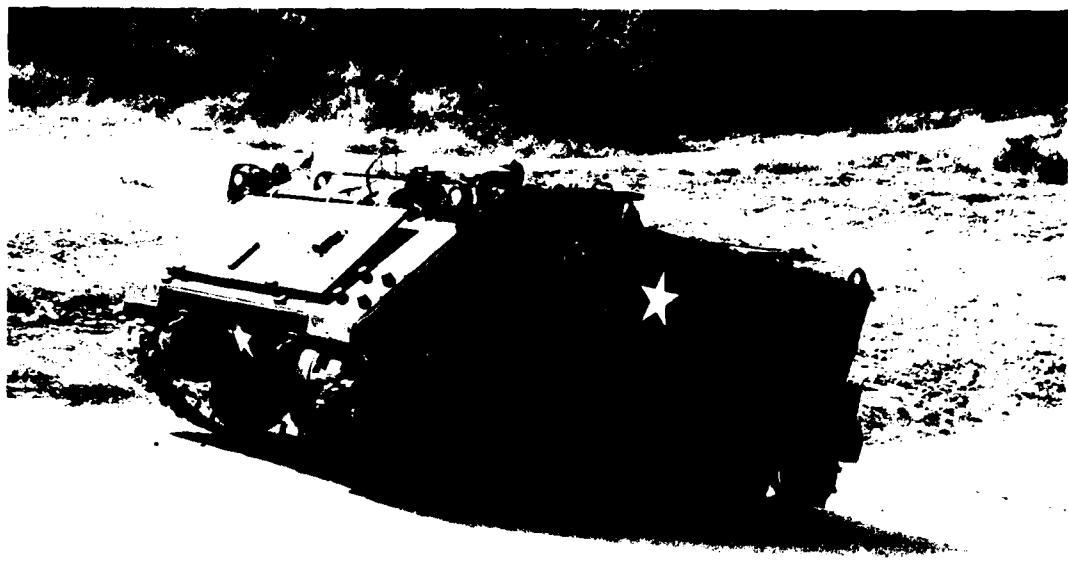


Photo 1. M113 APC

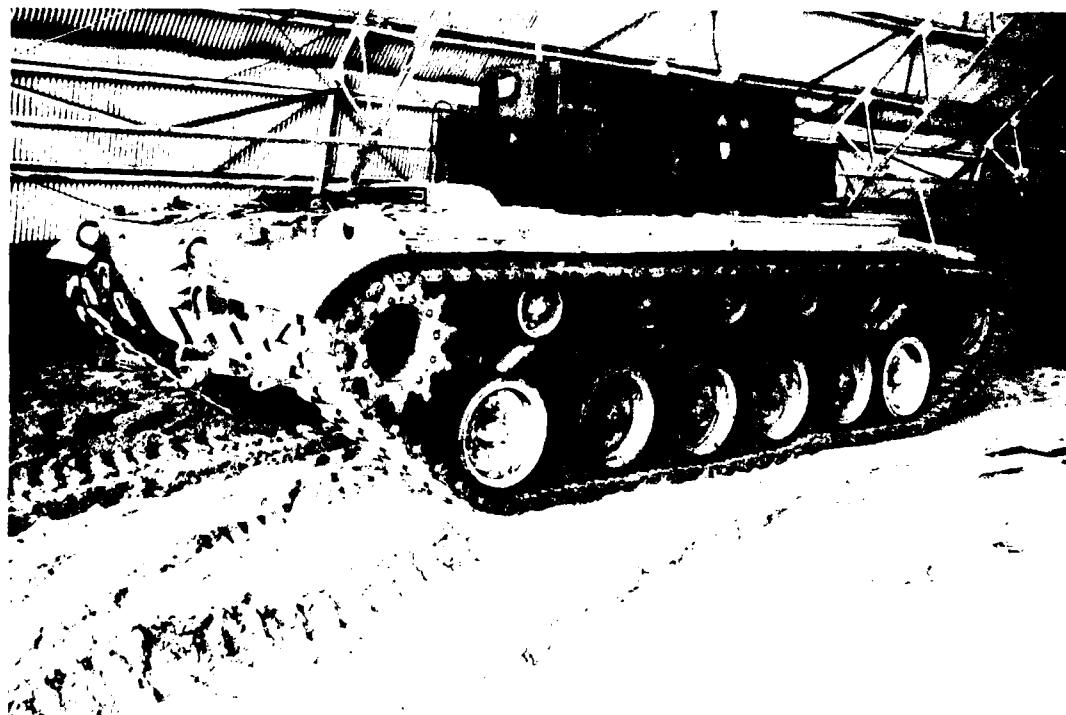


Photo 2. M48A1 tank



Photo 3. Ribbon bridge transporter



Photo 4. Flexmat I, single roll



Photo 5. Flexmat I, anchored on slope prior to traffic



Photo 6. Flexmat I, after removal from test site

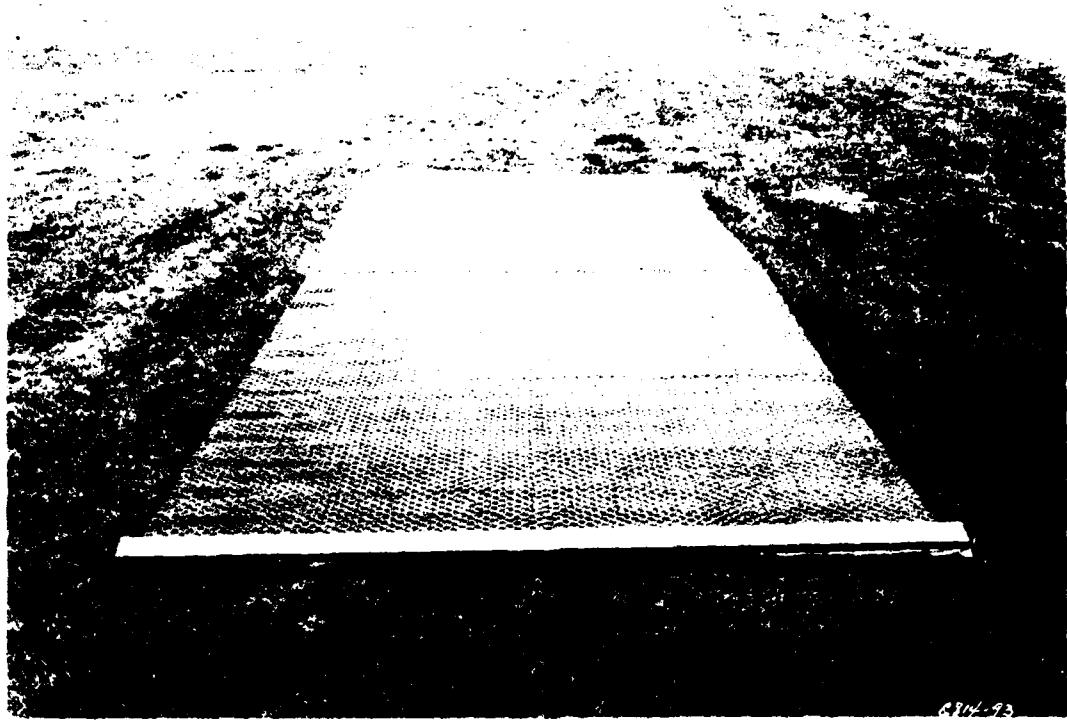


Photo 7. Flexmat II, showing aluminum tube and location of clamps



Photo 8. Flexmat II, being placed on 25 percent slope



Photo 9. Damaged Flexmat II, after removal from lake site



Photo 10. Close-up view of damaged Flexmat II



Photo 11. Close-up showing spacing of aluminum clips for Item 1, Flexmat III



Photo 12. Close-up showing spacing of aluminum clips for Item 2, Flexmat III

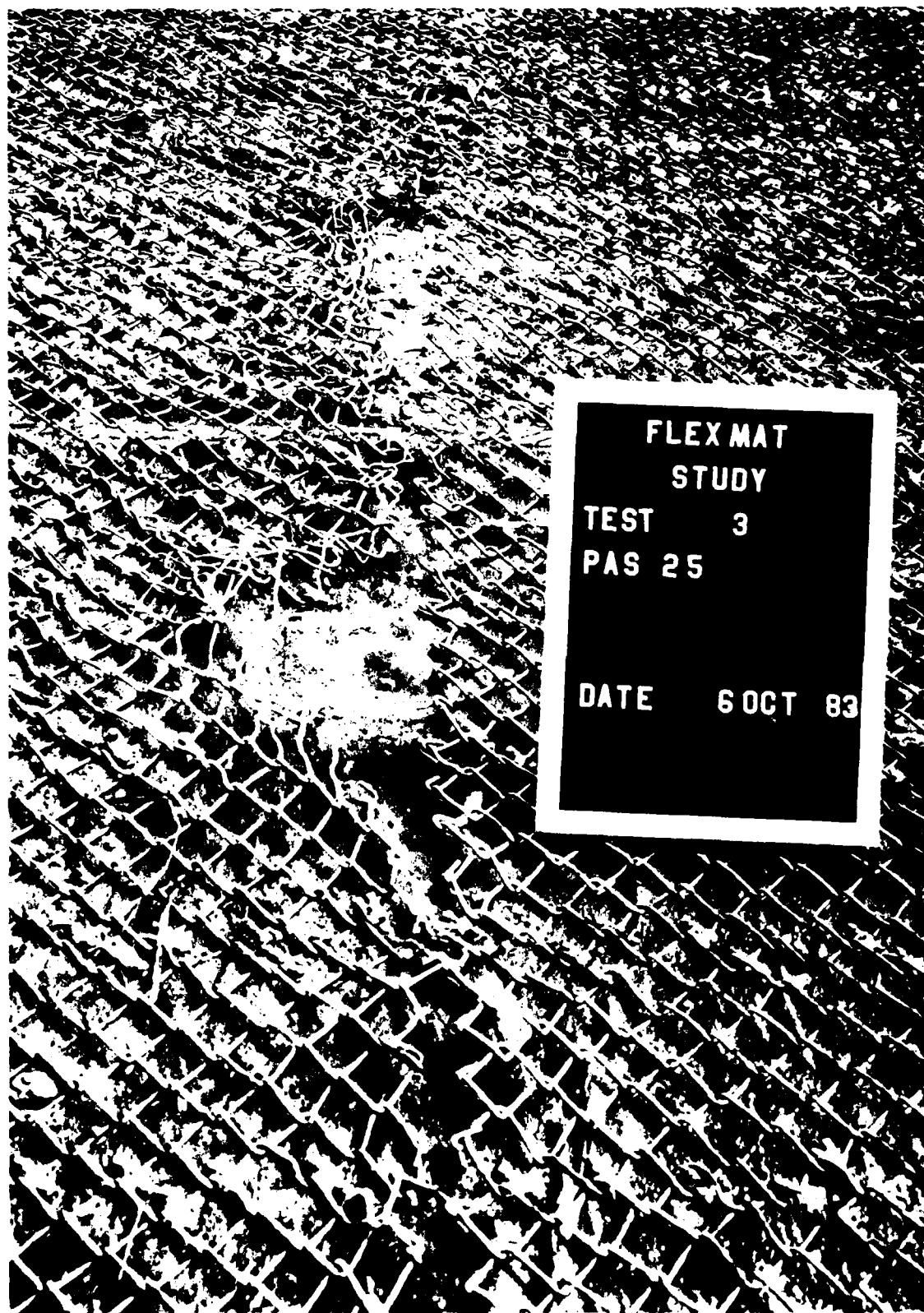


Photo 13. Close-up of damage at center line, Flexmat III

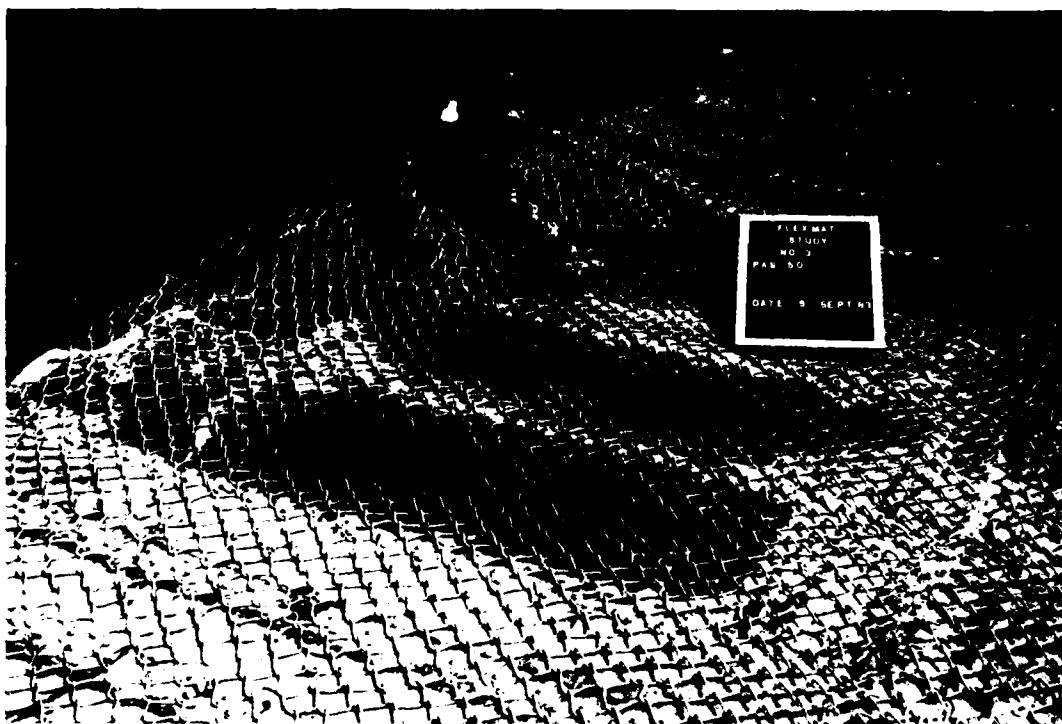


Photo 14. Damage caused by vehicle making side approach, Flexmat III

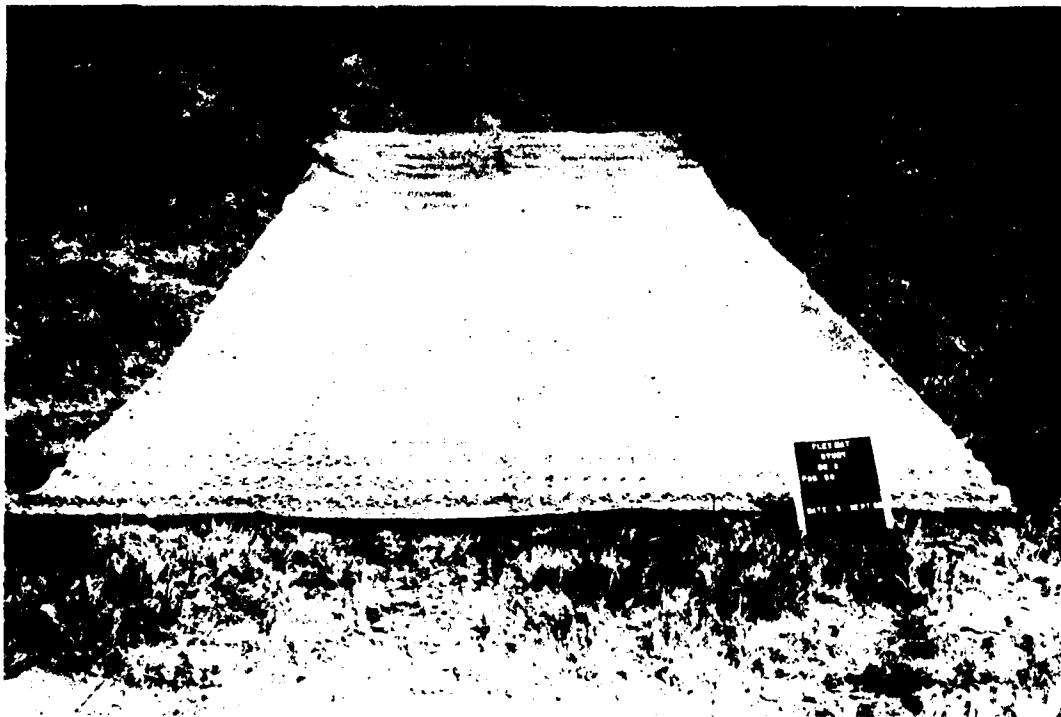


Photo 15. Flexmat III, after 57 passes with APC



Photo 16. Flexmat IV, showing guide markers deployed

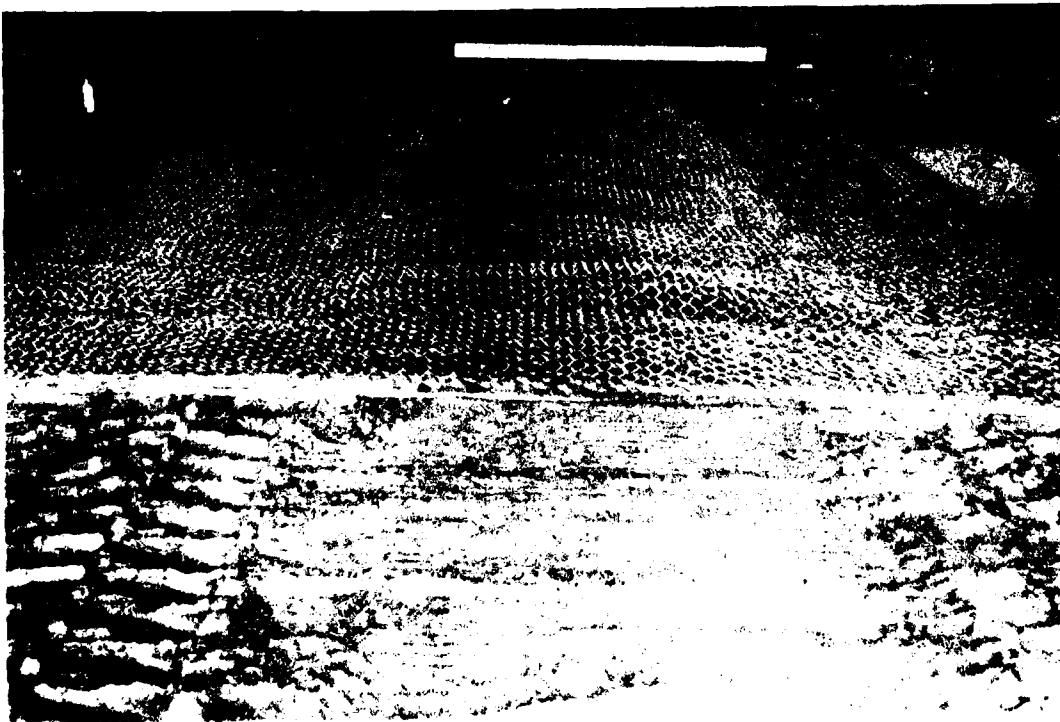


Photo 17. Flexmat IV, after 81 passes of mixed traffic

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